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Ionospheric Variability

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This report summarizes the results of a study of short term variations of the ionosphere. The digital ionograms used in this analysis were recorded at Brighton, Colorado, many of them at a high rate of 12 ionograms per hour and faster. The results show that oscillations of the electron density distribution take place in the F-region with varying amplitudes and with periods of a fraction of an hour. The oscillations are coupled with varying tilts. Rapid changes, mainly of the electron density, are also observed at E-layer heights and many records indicate that the echoes come from tilted sporadic-E patches with relatively small dimensions.

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CONTENTS

FIGURES

SUMMARY

This report summarizes the results of a study of short-term variations of the ionosphere. The digital ionograms used in this analysis were recorded at Brighton, Colorado, many at a high rate of 12 ionograms per hour and faster. The results show that oscillations of the electron density distribution take place in the F-region with varying amplitudes and with periods of a fraction of an hour. The oscillations are coupled with varying tilts. Rapid changes, mainly of the electron density, are also observed at E-layer heights and many records indicate the echoes come from tilted sporadic-E patches with relatively small dimensions.

INTRODUCTION

During the last sunspot maximum, 1980 to 81, a digital ionosonde developed by the National Oceanic and Atmospheric Administration (NOAA) (Grubb, 1979) and cosponsored by the National Science Foundation (NSF) was operated at Brighton, Colorado. The data recorded are of importance mainly for two reasons:

(a) The design and the concept of the system provide data of high accuracy

(b) Many of the ionograms were taken in rapid sequences of 12 ionograms per hour and faster.

This combination of high-accuracy and high-temporal resolution offers the opportunity to study details of ionospheric variations. At the time the ionospheric observation program in NOAA was terminated in 1981, very few data had been analyzed. When funds became available through the Naval Ocean Systems Center (NOSC) Independent Research (IR) program to conduct a systematic analysis of the data, the original records were borrowed from the World Data Center in Boulder, Colorado.

The ionosonde had the capability to record in digital form the travel time, amplitude, and phase of each echo reflected from the ionosphere at four receiving antennas. The receiving antennas were short dipoles located at the corners of a square with a diagonal length of 100 meters. In a typical mode of operation the two-channel receiver recorded the signals at two diagonally opposite antennas simultaneously and was switched to the other diagonal antenna pair in time to receive the echoes of the next pulse transmitted. The radio frequency was increased by 8 kHz and two more pulses were transmitted with the antenna switching sequence reversed. This way the change of the radio phase with frequency, which permits more accurate estimates of the echo travel time (virtual height), could be separated from the phase change with time, which gives the Doppler frequency or Doppler velocity. A phase comparison at the four antennas can be used to determine the angle of arrival of an echo, or in combination with the virtual height, to determine the apparent position of its reflection point.

F-REGION VARIATIONS

The important and surprising findings of this data analysis are the ever present oscillations of the F-layer coupled with strong tilts of the reflecting surface. The oscillations are clearly visible in the temporal changes of a variety of standard parameters, such as the critical frequency, the virtual height for a constant frequency, the height of maximum of the layer, etc. We found the most accurate and probably most representative indicator for F-region variations is the maximum usable frequency for a 3000 km propagation path, the MUF(3000), a parameter which can easily be derived from the vertical ionograms (Paul, 1988a). Figure 1 shows two examples of the daytime variations of this parameter. While a typical period on February 16 (bottom) was approximately 20 minutes, some longer periods with larger amplitudes were present on January 15 (top) in addition to the shorter oscillations. No explanation for the different magnitude of the variations could be found, but there is definitely no correlation with magnetic activity. There is convincing evidence (Paul, 1988b) that the variations observed are caused by acoustic gravity waves traveling through the F-region which means the temporal variations are coupled with spatial variations. The only information about spatial variations in the horizontal dimensions which can be obtained from the data of this monostatic observation technique is the deviation from vertical propagation. In figure 2 we compare the apparent positions of the reflection point for the two data sets which were used in figure 1. The apparent positions shown here are for the point where the MUF(3000) transmission curve is tangent to the ordinary echo trace which corresponds to a height approximately halfway between the lower edge of the F-layer and the height of the electron density maximum. We see the points are spread over a larger area for the data of January 15 (top) than for those of February 16 (bottom). The median zenith distance for the data in the top of figure 2 is 2.2 degrees and 1.5 degrees for the data in the bottom half of this figure. We can compute an estimate of the temporal derivative of the MUF(3000) simply by dividing the differences of consecutive data by the 3-minute time interval and obtain curves as shown in figure 3. The median magnitude of this quantity is approximately 6.9 MHz/hour for January 15 and 4.2 MHz/hour for February 16. The ratio of those two numbers is very close to the ratio of the median zenith distances for the two days and is quite different from the ratio of the median deviations from the mean MUF(3000). This comparison indicates that it is the temporal derivative of the MUF(3000) and not the quantity itself which permits us to obtain an estimate of the deviation from vertical propagation and therefore of the magnitude of F-region tilts. This relation was found to be true consistently with all the data sets available. Application of this relation for tilt estimates based on temporal variations requires that the sampling rate be sufficiently high (10 ionograms per hour or more) to avoid aliasing.

Usually the zenith and azimuth angles change slowly with frequency (height) within an ionogram. Occasionally such changes indicate a periodic behavior over a fraction of a period within the frequency (height) range of observation and sometimes an estimate of a vertical wavelength can be obtained.

In many cases the zenith distance is only a lower limit for the tilt angles in the vicinity of the reflection area. For example, the expansion phase of an acoustic-gravity wave at the height of the maximum causes a local reduction of the maximum electron density as can be seen in the variation of the critical frequency foF2. This
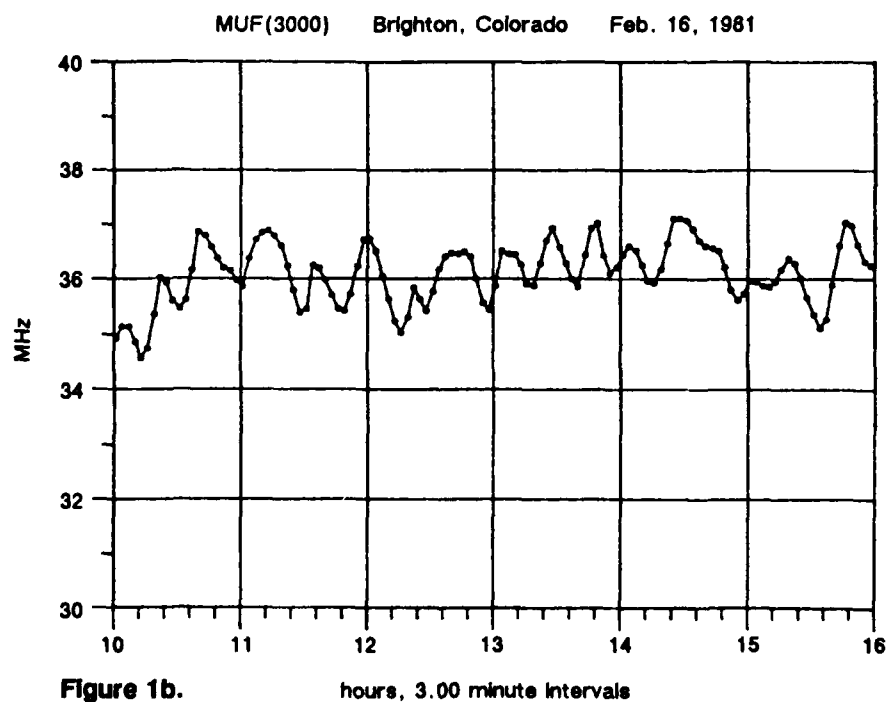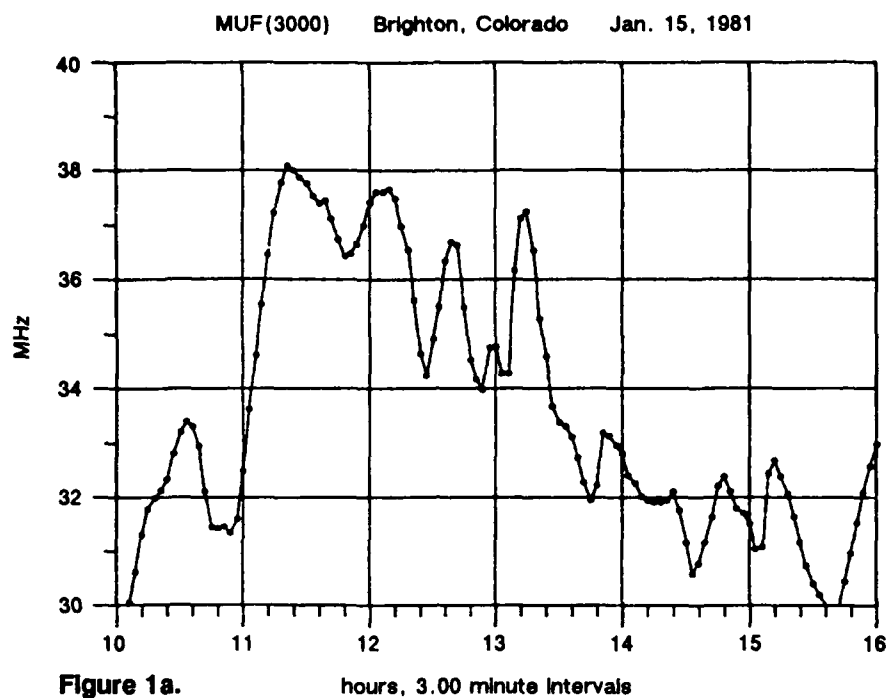
2

MUF(3000)   Brighton, Colorado   Jan. 15, 1981

Figure 1a.   hours, 3.00 minute intervals

MUF(3000)   Brighton, Colorado   Feb. 16, 1981

Figure 1b.   hours, 3.00 minute intervals

Figure 1. Variations of the propagation parameter MUF(3000) for an active day (top) and a quiet day (bottom).

3

Apparent Position of the Reflection Point
Brighton, Colorado   Jan. 15, 1981

Figure 2a.   km, 3.00 minute intervals

Apparent Position of the Reflection Point
Brighton, Colorado   Feb. 16, 1981

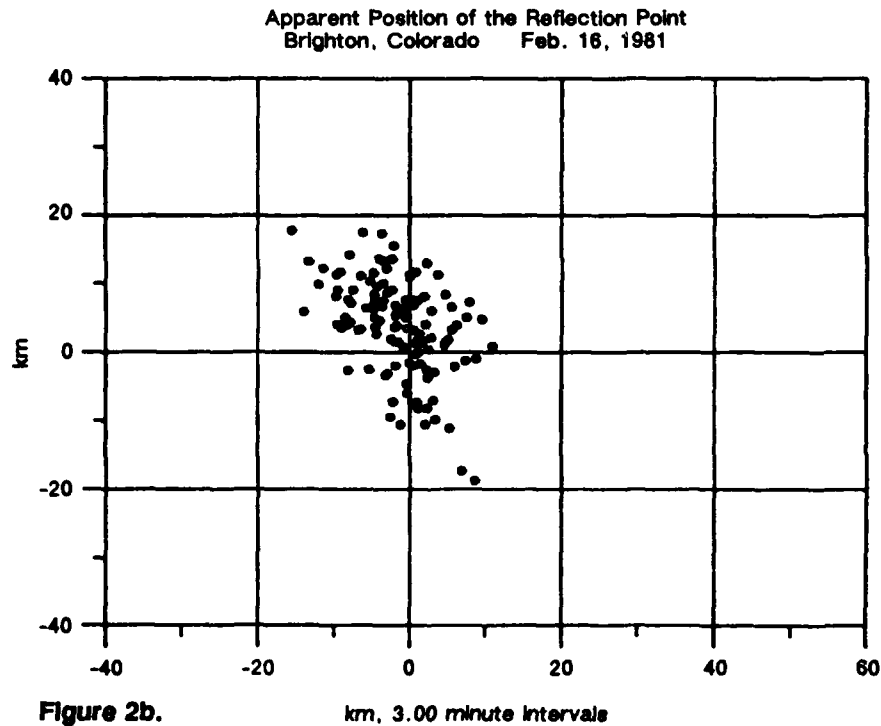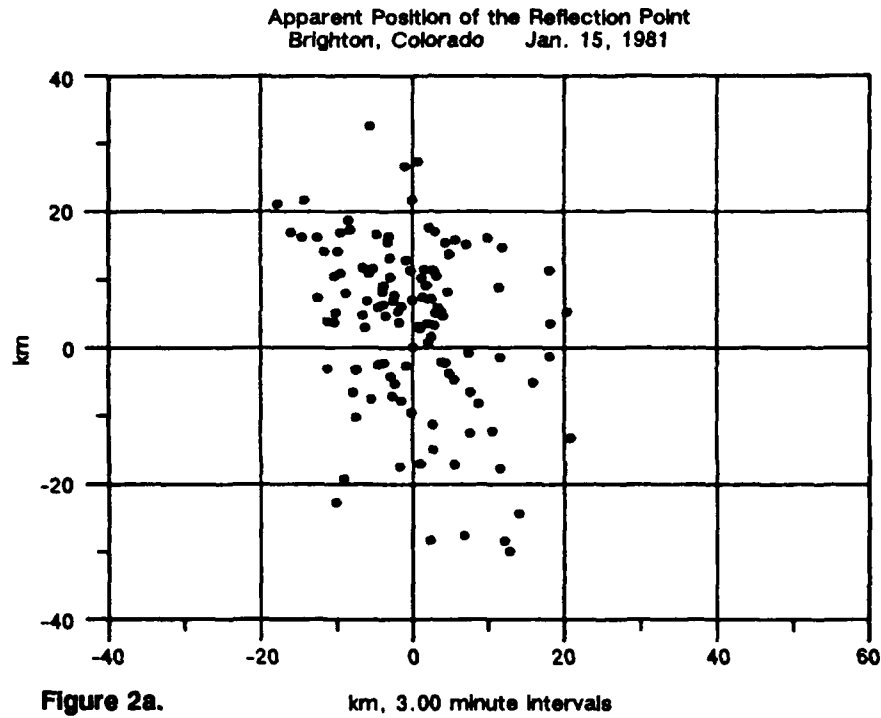
Figure 2b.   km, 3.00 minute intervals

Figure 2. Deviations from vertical propagation as indicated by the apparent positions of the reflection points.

4

Time derivative of MUF(3000)
Brighton, Colorado   Jan. 15, 1981

Figure 3a.   hours, 3.00 minute intervals

Time derivative of MUF(3000)
Brighton, Colorado   Feb. 16, 1981

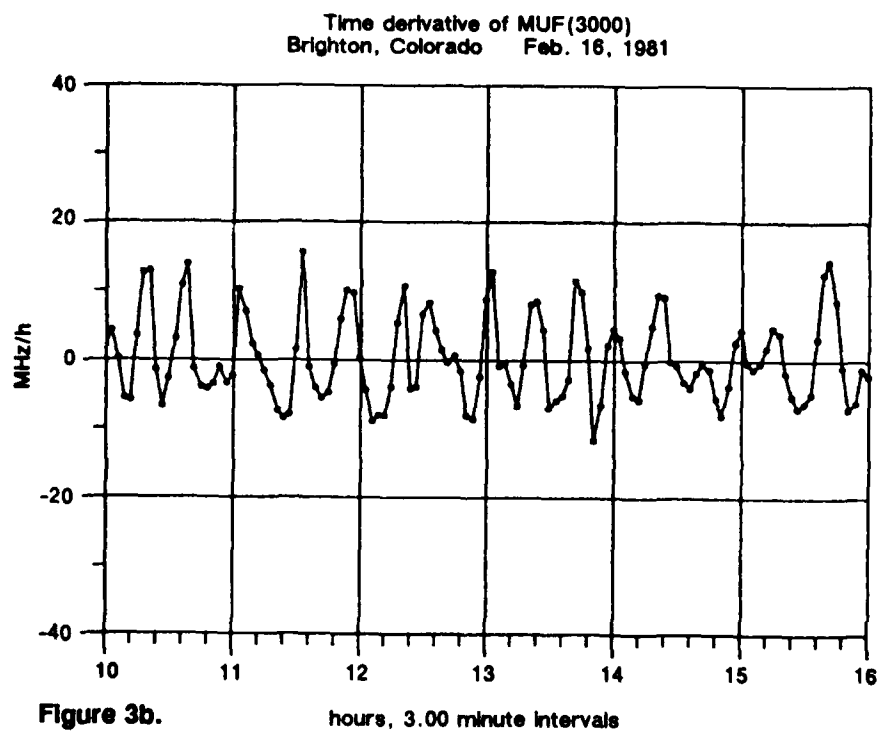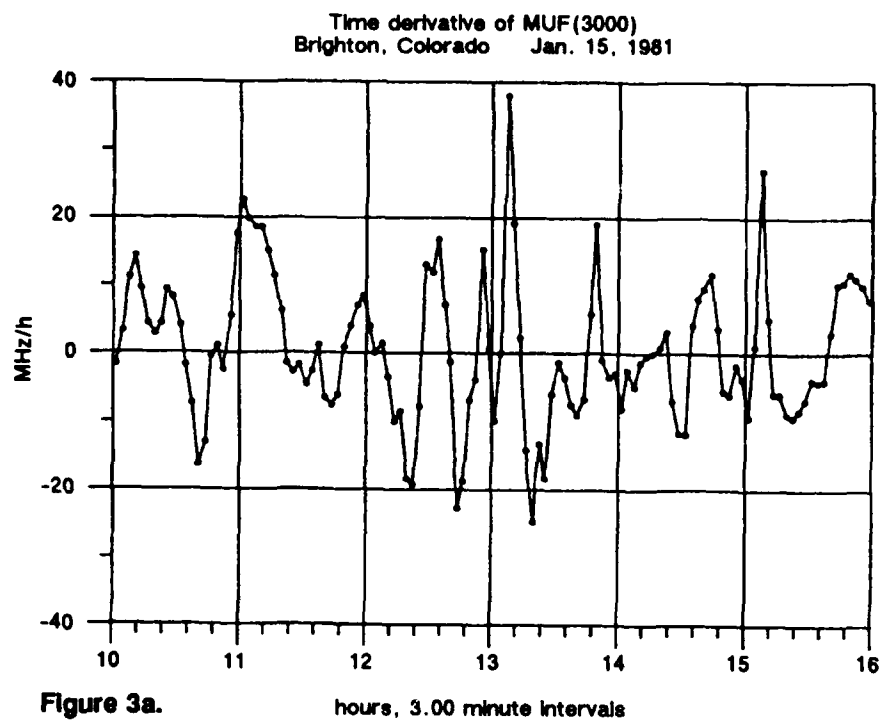**Figure 3b.**   hours, 3.00 minute intervals

Figure 3. Temporal derivative of the MUF(3000).

means for a short period of time a horizontal gradient exists at the height of the maximum and the ray direction of signals reflected may become almost horizontal for frequencies close to the penetration frequency. The integrated effect of this kind of structure results in an increase of the zenith angle with increasing frequency which indicates a strong tilt, but still underestimates the actual tilt angle in the vicinity of the reflection point. While the variations of the critical frequency and of the MUF (3000) have some direct effect in the conventional sense on HF-propagation, local tilts, depending on their orientation relative to the propagation direction, can have a much stronger influence (e.g., overlong propagation distances).

The temporal variations of the MUF(3000) are a combination of a vertical motion of the F-layer and a change of the electron density. Both variations take place in some periodic fashion but are not in phase (Paul, 1988b). This phase lag indicates that a periodic deformation of the layer takes place and standard parameters like critical frequency, height of maximum, and half-thickness of the layer which are obtained by extrapolation are sometimes ill defined which also means isolated observations of such parameters may not be representative for a longer period of time.

SPORADIC-E VARIABILITY

The significant results here are the short life time (observation time) and the large tilt angles of this layer (Paul, 1988c). Figure 4 shows ftEs, the highest frequency of echoes reflected from E-region heights for a 2-hour period during daytime. Ionograms were recorded continuously at a rate of 77 ionograms per hour. Most of the data simply show the regular E-layer critical frequency, foE. There are however several instances where ftEs suddenly increases to twice the value of foE or higher for the short duration of 1- or 2-sampling intervals. Only a few hours of data were recorded at such a high sampling rate, but ionograms recorded at a somewhat slower rate show a similar behavior. Of 4019 ionograms recorded in 3-minute intervals, 1013 showed sporadic-E traces and 15 percent of those ionograms were isolated events where no sporadic-E was recorded in the preceding and following ionogram. Approximately 32 percent of the sporadic-E observations formed short sequences of 5 or less consecutive ionograms. No explanation for those rapid changes could be found and it is not clear whether the formation and decay of a layer can take place in such a short period or small patches of ionization move rapidly through the observation field. On the other hand a few cases were found in this data set of 20 ionogram per hour recording rate where sporadic-E was observed in consecutive ionograms for several hours. While these long sequences showed continuity in time in terms of existence of sporadic-E, there were often significant changes of the apparent position from one ionogram to the next one. Those observations are likely to indicate that the proper condition for the formation of sporadic-E existed for a longer period of time and are less likely to prove that an individual layer lasted that long.

The existence of small patches of ionization is supported by the frequent observation of layers with large tilt angles, which for physical reasons can only exist over a limited height range. A total of 1911 sporadic-E layers were found in the 1013 ionograms mentioned above. In 999 cases the average zenith angle of the echoes was 10 degrees or less. In 409 cases the deviation from vertical propagation was between 10 and 20 degrees and more than 20 degrees for the remaining 503 cases. We point out that contrary to F-layer reflections, there is little bending of a ray reflected from
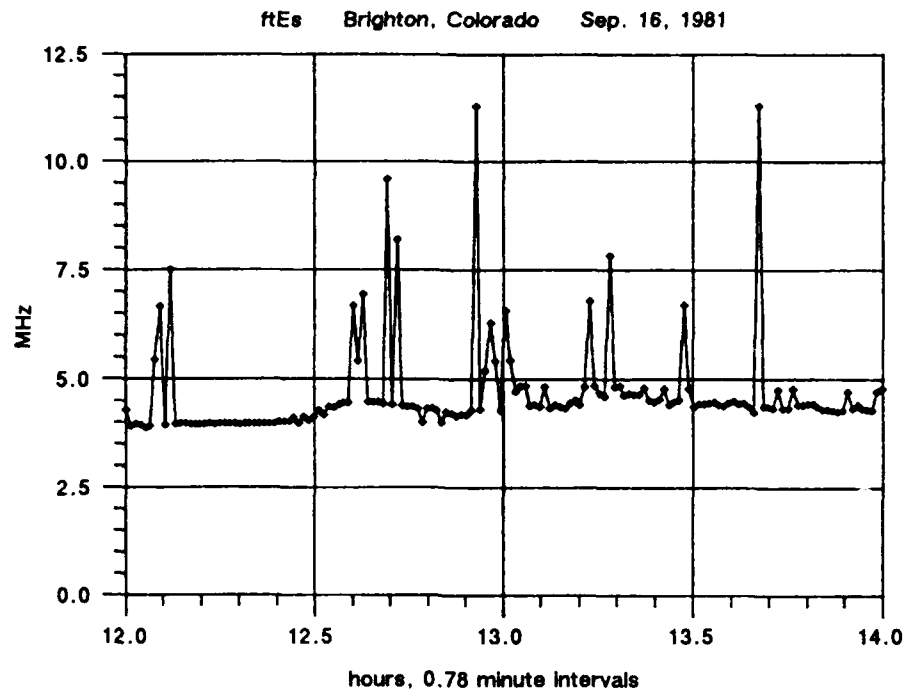
Figure 4. Top frequencies of sporadic E-layers embedded in the regular E-layer.

a sporadic E-layer, since the layer is so thin. For this reason the angle of arrival is a direct measure of the tilt angle. The presence of two or more Es-layers in one ionogram also implies a relative small size of each layer or a corrugated structure with a scale size not to exceed a few tens of kilometers.

No preferred orientation of the tilts could be found. The apparent reflection points showed a rather uniform azimuthal distribution. This can be seen in figure 5 where the average position of all Es-layers over a 24-hour period are plotted.

When large zenith distances are observed the so-called virtual heights have to be interpreted as ranges and have to be corrected correspondingly. This correction applied to the data sample described above lowered the median virtual height by 4 to 107 kilometers and also narrowed the height distribution of sporadic-E.
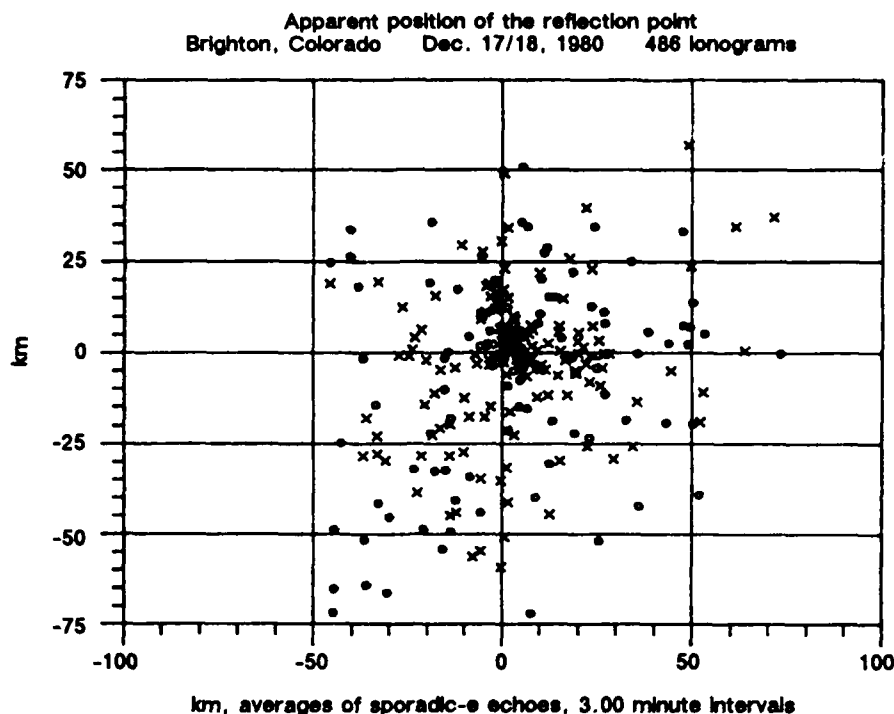
Figure 5. Apparent average positons of sporadic E-layers over a 24-hour period indicating strong tilts (x observed in the extraordinary propagation mode, o observed in the ordinary mode).

CONCLUSIONS

Typical time scales for the F-layer are on the order of a fraction of an hour. For this reason a minimum sampling rate of 12 ionograms per hour is required in order to obtain a correct description of the temporal variation of the F-layer. Based on the rate of change of well defined standard parameters in combination with reasonable assumption about the velocity of acoustic gravity waves, we conclude that local tilts can exist at any time of the day (or night) which are of the same magnitude as those observed during sunrise or sunset (Paul, 1985). Deviations from vertical propagation of 10 degrees or more are frequently found, at least for frequencies close to the penetration frequency. The area over which such local tilts may exist is likely much smaller than the sunrise or sunset zone. While the orientation of the tilts during sunrise and sunset are predictable, this orientation is not true for tilts coupled with gravity waves since their velocities (magnitude and direction) cannot be determined from monostatic observations.

8

Typical time scales for sporadic-E can be much shorter than those for the F-region, but are of a different nature. While most of the F-region variations are periodic, no periodic phenomena were found in sporadic E-layers. Life times or observation times of sporadic-E cover a larger range than the F-layer periodicities, from less than 1 minute to several hours. Tilts of sporadic E-layers can be larger than F-layer tilts and have similar effects on HF propagation.

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